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File No. 95-129
6 November 1995
MEK:NeXT
Total Pages: 32
Total Figures: 0
Total Tables: 5
SP No. 359-95

INTERNAL MEMORANDUM

To: J. A. Hager, F. W. Symons, L. H. Sibul, C. S. Byington, R.W. Chen, J. N. Duncan, J. E. Dzielski, A. K. Garga, J. M. Grimplin, D. L. Hall, R. J. Hanson, C. P. Janota, L. L. Holliday, S. Phoha, F. H. Reeser, J. R. Sacha, R. K. Young, ARL Files (2)

Info: L. R. Hettche, M. F. Amateau, J. H. Beebe, R. E. Biancardi, M. L. Billet, J. C. Conway, P. E. Denney, R. F. Erdley, R. R. Goodman, D. B. Herbert, D. H. Kiely, E. G. Liszka, R. J. Lunnen, C. C. Merchant, W. W. Moyer, C. R. Philbrick, S. Rao, J. L. Spiesberger, R. Stern, D. E. Thompson, A. N. Vavreck, H. E. Watson, C. J. Wilson, C. R. Zentner, ARL Prog Files

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Subject: ***Workstation Technology Trends and Implications***

References: see page 29.

Abstract: Computer technology evolution is on the verge of redefining the meaning of "computer" as well as the human-computer relationship—which implies profound changes in the capabilities and operational procedures in systems such as the Navy's Mission Planning Systems. Herein, we examine the evolution of current technologies as well as the applicability of emerging technologies within the context of the DoD's information processing needs. The implicit assumption is that an awareness of technology trends will facilitate system designs which exploit those technologies for improved system performance as well as permit an evolutionary growth paths for inclusion of emerging technologies as they mature.

The near-term (five year) technology projection essentially estimates the performance of the DoN Tactical Advanced Computers (TAC-x) which will be available to the next generation Tactical Air Mission Planning System (TAMPS). However, the longer-term projection indicates profound changes in computing technology—and, by extension, profound changes in the

mission planning process and performance.

To exploit the emerging technologies, distributed object-oriented computing—emphasizing modularity, information encapsulation, and open systems technology—should be explored via a distributed computing testbed. Additionally, the long-term implications and applicability of changing computing paradigms DoD information processing should also be addressed.

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1. Introduction

Computer technology evolution is on the verge of redefining the meaning of “computer” as well as the human-computer relationship—which implies profound changes in the capabilities and operational procedures in systems such as the Navy’s Mission Planning Systems. Herein, we examine the evolution of current technologies as well as the applicability of emerging technologies within the context of the DoD’s information processing needs. The implicit assumption is that an awareness of technology trends will facilitate system designs which exploit those technologies for improved system performance as well as permit an evolutionary growth paths for inclusion of emerging technologies as they mature.

1.1 Motivation

The Navy’s workstation-based *Tactical Air Mission Planning System* (TAMPS) is currently in its sixth generation. Future generations will also be workstation-based; however, the definition of “workstation” will be changing with the advancing state-of-the-art. The intent of this analysis is to characterize the workstation of the year 2000—which is the anticipated deployment timeframe of the next generation of mission planning systems—as well as identify any technology trends which may be applicable to subsequent generations and, therefore, should be considered as evolutionary development paths.

The three main components characterizing workstation technology are:

- data & information processing;
- computer-computer interaction; and,
- human-computer interaction.

Thus, a workstation is a composite—software, networking, and human interface as well as the CPU chip and hardware. Developments in hardware, software, and networking capabilities will facilititate improved mission planning as it is currently defined. These developments will also enable new computating paradigms which will, in turn, change and improve the mission planning process. Thus, in predicting the capabilities of future workstations, there is an evolutionary aspect (discussed in Chapter 3) as well as a revolutionary aspect (addressed in Chapter 4). The evolutionary and revolutionary aspects are discussed within the context of the mission planning application.

1.2 Emerging Computing Paradigms

As currently defined, a workstation incorporates a CPU and associated hardware, keyboard and mouse (or equivalent) for human input, a monitor and speakers for human output, and a network interface for data transfer to other computers. The underlying computing paradigm is computer-centric—in the sense that the human must adapt to the limitations and configuration of the workstation. However, alternate computing paradigms will be permitted in the near future due to emerging technologies. Technologies nearing operational maturity include: speech recognition/voice input, human language understanding, head/eye tracking, flat-panel displays, handwriting recognition/pen-based input, intelligent agents, high-speed networking, multi-level security, etc.

Three emerging computing paradigms will mature within the next 5–10 years:

computer-centric: continuing the current workstation paradigm, future instantiations will incorporate virtual reality to integrate the user into the computer (virtual) domain.

human-centric: also known as ubiquitous computing, it aims to push the computer into the background. Examples include pagers, cellular phones, PDAs, and smart badges; this paradigm requires the networking of many computers with relatively little artificial intelligence.

team-centric: similar to the perfect butler, the computer will assume some of the burden of data monitoring and implementation of details. This approach features intelligent agents (i.e., artifical intelligence) as well as multi-modal human interfaces.

As discussed in Chapter 4, each philosophy/paradigm is valid and useful—and future mission planning systems will use aspects of each. Implementation of the alternate paradigms exploits the *synergy* between emerging technologies and will produce improved information processing systems. Although the full-fledged implementation of these paradigms will radically differ from the current human-computer model, the initial simplistic implementations will enable a significant increase in performance and net productivitiy.

1.3 Organization

Chapter 2 briefly reviews the TAMPS operational characteristics as well as the design and development issues associated with TAMPS 7.0. In addition to timeliness and accuracy of strike and path planning, the TAMPS 7.0 design must consider development cost and risk, cross-system integration, and scalability. The subsequent technology assessment is done within the context of the mission planning application.

Workstation2000" might be an alternate title for Chapter 3 since the focus is evolutionary changes to the current workstation model. To some extent, this involves extrapolating the capabilities of the Navy's current Tactical Advanced Computer Four (TAC-4) workstations to the TAC-5 or TAC-6 generation—principally focussing on their computational, display, and networking capabilities. The projected capabilities and their implications for mission planning systems as well as general system design and performance is considered.

However, as mentioned previously, maturing technologies may redefine the term "workstation." These technologies are reviewed along with their potential impact to mission planning in Chapter 4. The incorporation of the alternate computing paradigms into the mission planning process are also considered in this chapter.

Finally, in Chapter 5, the technology trends and their implications are summarized and potential research thrusts identified.

2. Tactical Mission Planning

Mission planning success is contingent upon knowledge *coordination*—where the applicable knowledge concerning resource availability and capability, threat characteristics and deployment, weather, campaign objectives, etc. may be distributed among disparate sources. The objective of the mission planning system (MPS) is to assemble plans based upon the best available knowledge. The technology trend towards distributed computing facilitates a *workflow management* approach which increases the exploitation of the available knowledge while simultaneously simplifying knowledge synchronization and improving system evolvability.

In this chapter, we briefly review the operational objectives of the next-generation DoN Tactical Air Mission Planning System, TAMPS 7.0, as well as the general development objectives for mission planning systems.

2.1 TAMPS Objectives

When deployed, the seventh generation of the Tactical Air Mission Planning System, TAMPS 7.0, will be an automated system to plan strikes at the unit and force levels using both strategic and tactical assets. These assets include:

- aircraft (fixed and rotary wing);
- stand-off weapons;
- UAVs;
- Tomahawks;
- Special Operations Forces;
- Battle Group & Force Level assets;
- etc.

The primary users and operators of TAMPS 7.0 are the strike leaders and their planning teams. To develop the strike package, TAMPS will interface with related systems such as:

TEAMS:	Tactical EA-6B Mission Support System
TSCM:	Tactical Strike Coordination Module
AFMSS:	Air Force Mission Support System
CTAPS:	Contingency Tactical Automated Planning System
JMCIS:	Joint Maritime Command Information System

Using these resources as well as internal knowledge of the weapon capabilities, threat characteristics, order-of-battle, etc., TAMPS will address its primary roles of:

- interactive multiple-mission planning support;
- route planning;
- plan documentation generation; and,

- electronic data load generation for weapon systems.

Additionally, TAMPS will satisfy three secondary objectives:

- integrated/coordinated strike planning;
- C^3I support; and,
- mission replay/analysis.

TAMPS systems will be deployed aboard ship, in training facilities, at shore-based sites, as well as with forward units using standard Navy tactical computers. Since the Tactical Advanced Computers (TAC) evolve along with commercial computing advances, the design of TAMPS should not be constrained by the performance of the current generation TAC-4 systems. One of the implicit goals of this analysis is to project the capabilities of a TAC-5 or TAC-6 system so that appropriate algorithms and architectures may be chosen during the design process.

The typical TAMPS 6.0 configuration contains three to six workstations; however, the TAMPS 7.0 system may feature more workstations to achieve greater system performance and robustness—or fewer or portable workstations for mobile deployments or special deployments. An additional system design requirement to support multi-level security (MLS) also implies greater system and networking complexity.

2.2 Design and Development Objectives

As with most DoD information processing, the “perfect” mission planning system must satisfy conflicting objectives:

- maximize operational performance;
- minimize operational system cost;
- minimize system development cost and risk;
- minimize software maintenance costs;
- maximize software reuse in future systems; and,
- maximize flexibility and scalability.

To some extent, the continuing improvement in hardware and software technology helps to achieve these objectives; however, new technology permits new solutions which, in turn, increase expectations so that the “perfect” mission planning system will remain an unattainable goal.

The most important design criteria is system performance. The fidelity and accuracy of the developed plans are contingent upon using high quality information and using all available resources—including the capabilities of the human mission planners. Thus, to maximize system performance, the mission planning system must

- exploit remote systems and data and
- have a “good” human-computer interface.

Of course, the system must also effectively use the information contained within the local domain. Remote system exploitation involves extracting salient data (e.g., the most recent weather, imagery, etc.) as well as tasking remote processing (e.g., to determine the logistical implications of a proposed mission plan)[1]. A natural and effective human-computer interface (HCI) improves mission planning performance by allowing the human to easily develop,

[1] Object-oriented programming and database technologies coupled with high-speed networks facilitate operating in such a distributed processing mode. The CORBA (Common Object Request Broker Architecture) technology is also a key aspect since it introduces a layer of abstraction which is useful in the dynamic configuration changes typically associated with mission planning operations.

review, interpret, and refine potential or previous missions—and provide the "big picture" perspective. As noted in the following chapters, some of the emerging HCI paradigms and multi-modal input-output technologies will dramatically improve the quality of HCI relative to that of current systems.

To some extent, there is no substitute for computing horsepower—the ability to move, store, manipulate, and display bits is integral to the mission planning process. As technology advances, the cost of moving and processing bits continues to decrease while the processing ability increases. That said, the economies of scale associated with mainstream commercially-successful CPUs—such as the Pentium and PowerPC chips—coupled with shrinking defense budgets will continue to push the DoD towards COTS (Commercial Off The Shelf) systems. However, this approach could result in a Potemkin savings unless long-term issues of operating system, development tools, evolutionary paths, and open systems portability are considered.

Custom processing systems such as mission planning systems are *legacy systems* in the sense that they represent a significant development effort as well as a corresponding commitment in terms of deployed hardware and system resources. To distribute the cost as well as exploit validated and refined systems, the developed software should be *reusable* with future processing systems and applications. The advent of high-speed networks imply that future systems should employ distributed computing and object-oriented programming and database systems to allow for evolutionary system refinement. Such an approach also facilitates external system exploitation of the developed capability—consistent with the trend towards workflow management architectures.

Future software, hardware, and systems technology will enable novel mission planning operational procedures—as is discussed in the following chapters. However, *current* open systems technology coupled with distributed computing concepts will help to ensure that developed legacy systems can be incorporated into future processing systems.

3. Evolutionary Technology Trends

The concept of a “workstation” currently incorporates a high-resolution display, fast processor, network interface, multi-tasking operating system, and accessories such as keyboards, mice, track balls, disk drives, CD-ROMS, etc. The technologies associated with the conventional workstation continue to evolve and improve; however, there are technologies on the near horizon which will change the computing paradigm and, therefore, change the definition—if not the applicability—of a “workstation.”

The focus of this chapter is the evolution of the conventional workstation technologies whereas technologies which *may* be ready to transition from the research environment to an operational mission planning system are the topic of Chapter 4.

3.1 Technology Options

Although it is tempting to characterize workstations by their ability to manipulate *bits*—i.e., the speed of the underlying CPU—the true purpose of a workstation is to manipulate, create, and present *information*. Hardware performance is important since advances in processing and interfaces enable software and interface technologies which would not be viable with less capable systems—e.g., intelligent agents, ubiquitous computing, and virtual reality.—as is discussed in more detail in Chapter 4.

The system development process involves choosing the appropriate technologies to achieve the desired system performance and development risk. The technology options may be partitioned as:

- inter- and intra-system interfaces;
- processing hardware;
- human interfaces;
- software operational environment;
- processing algorithms; and,

- system packaging.

Table 3-1 lists potentially applicable technologies within each of the identified option categories. Although there are many exciting software and algorithm technologies directly applicable to mission planning systems (e.g., linear matrix inequality theory and artificial

Table 3-1: Technology Options

Interfaces	• data/objects (CORBA, DoD, DoN, etc.) • physical (wire, fiber, wireless, etc.) • architectures (client/server, peer-to-peer, etc.) • devices (SCSI, PCI, CAN, etc.)
Hardware	• network/system architectures • CPUs & configuration • resources (RAM, disk, etc.) • network (ATM, Fiber-Channel, etc.) • interfaces (incl. network bandwidth)
Human Interfaces	• input (keyboard, mouse, eye tracking, voice, pen, etc.) • output devices (displays, sound, tactile, etc.) • interface paradigms (ubicomp, VR, intelligent agents)
Software Environment	• multi-level security • reliability & availability • resource-independence (i.e., portability & scalability • distributed processing • object-oriented software & databases • development standards (e.g., TAFIM)
Algorithms	• knowledge representation • simulation modelling (path planning) • distributed simulation • virtual reality (planning, training, & development) • training & documentation
Packaging & *Systems*	• displays & interfaces • portability & characteristics • operational environment • application modules (HW/SW/network units) • survivability

biologies) which hold the promise of improved system performance, these are outside the scope of the current chapter. Rather, we shall focus on the physical and the generic—i.e., the processing hardware, network, human-interface, and software environment.

A common theme of Table 3-1 is the need for *standards*—in terms of database interfaces, network protocols, hardware interconnects, software objects, displays, and input/output devices. Selection of appropriate standards is a critical design choice for the mission planning development because of the scalability requirement to support a variety of fixed and mobile configurations as well as the need to integrate complementary systems and their information into the developed plans. Standards can also be a help—or, a hinderance—for system evolution to incorporate new technologies.

3.2 Workstation Technology Projection Summary

Workstation Technology Projection Summary

Table 3-2 summarizes the capabilities of current TAC-4 high performance workstations, the current 1995 *workstation* technology limits and a near-term, year 2000, projection of workstation and associated hardware and network capabilities. Projection of computing capacity is especially difficult—and prone to under-estimation since the current doubling of performance every 18–24 months will be augmented by the trend to multiple-processor architectures. Essentially, this corresponds to implementation of current super-computer concepts on the desktop.

In addition to compute capacity, one of the most significant trends is the increased network bandwidth and flexibility offered by fiber-optic channels and the asynchronous transfer mode (ATM) protocol. Since ATM is a scalable protocol, the current systems having capacities of 100–163 Mbps can be scaled up to the current 12 Gbps synchronous optical network (SONET) capacity. Obviously, this is a significant change from the nominal 10–100 Mbps ethernet capacity. This increased capacity permits new client/server architectures as well as the timely transfer of large data segments and graphics. In fact, the increased network bandwidth will facilitate *distributed processing* algorithms which implement the multi-processor workstation architectures on a enterprise-wide basis; essentially, the ensemble of computers within group, plant, company, etc. act as a supercomputer satisfying the needs of the individual users on a dynamic and adaptive basis. Thus, within the context of the mission planning application, remote systems may be exploited (tasked) to provide data or processing rather than requiring that capabilities be replicated across systems.

The third major technology advance which will occur within the next 5 years will be the advent of large, high-resolution, flat-panel displays. This trend is being pushed by the commercial advent of high-definition television (HDTV) and its 16:9 aspect ratio and maximum 1929x1024 pixel resolutions. Since these displays will occupy a much smaller footprint than that of the current 70 pound 21-inch CRT technology, new flexibility will be offered in system layout as well as permitting multiple large displays to be associated with each workstation.

Although the technology may not be mature enough for inclusion in the TAMPS 7.0 development, the combination of increased compute capability with flat-panel display technology should result in PDA-type *workslates*—essentially corresponding to greatly enhanced Apple Newtons featuring large, high-resolution pen-based interfaces and speech recognition technology. This evolution should redefine the concept of a portable computer and will permit novel auxiliary processing. Presumably, such systems would integrate into flight systems to permit a mobile (pilot's assistant) mission planning system for use during strikes.

Workstation Technology Projection Summary

The projected increases in memory density, storage capacity, archiving technology, and multi-media capabilities represent evolutionary rather than revolutionary advances. Although

TABLE 3-2: Workstation Performance Trend Summary

Parameter	*TAC-4 Performance*	*1995 Limit*	*2000 Projected Environment*
Compute Power	• HP J210 • 159 SPECint92 • 266 SPECfp92	• 341 SPECint92 • 513 SPECfp92 • RISC	• multi-processors • VLIW & RISC • 1,000+ SPECint92 • 1000+ SPECfp92 • 50%/year growth
Memory	• 64 MB–1 GB	• 64 MB–1 GB	• 1–8 GB
Disk Storage	• 1 GB • 10 GB (server)	• 2–9 GB • 7–9 ms access times	• 10–100 GB
Display	• 1–2 monitors • 19-inch CRTs • 1600x1280 resolution	• 21-inch displays • CRT technology • multiple displays	• flat-panel displays • 40-inch+ displays • 1929x1024 pixels; • HDTV aspect ratios • integrated monitors
Input/Output	• keyboard • mouse/trackball	• multi-media • 3-D graphics	• speech recognition • pen input • eye tracking • virtual reality
Operating Systems	• HP-UX • X-Windows	• Unix • X-Windows • Mach • OPENSTEP	• Java • Plan 9 • object-oriented • multi-level security
Networks	• ethernet-based • 10–100 Mbps • router technology	• ATM-based • Fiber Channel • 163 Mbps • switch technology	• ATM-based • 0.163–12 Gbps • wireless networks
Workstation *Characterization*	• desktop • rack-mounted • portable	• same	• PDAs • workslates • workdesks
Data & Software Transfer & Archiving	• Tape • CD-ROM • floppy	• writable CD-ROM	• Network • high-density, writable CD-ROM
Portable Systems	• 640x480 pixels • 525 MB disks • 128 MB RAM • 52 SPECint92 • 81 SPECfp92	• 1024x768 pixels • 2.4 GB disks • 140 SPECint92 • 112 SPECfp92	• 1280x1024 pixels • pen-based interfaces • speech recognition • wireless interfaces

significant and necessary to support the impending revolutionary technology, they do not represent paradigm shifts in *workstation* technologies.

Projecting computer capability is a risky proposition and prone to *under*estimation due to the impending implementations of multi-processor architectures and the related potential for distributed processing. Conversely, the physically induced limits of current technology with respect to clock speeds, transistor size, and chip density is being reached; however, if quantum-effects-based devices mature, three orders of magnitude of chip performance may be in the mid-range future. Such devices *will* induce revolutionary changes.

Finally, recall that Table 3-2 was derived using the concept of a workstation as it is currently defined. While that definition will likely continue to be valid for the next five years, advances in information technology will introduce new paradigms for computer architectures as well as human-computer interfaces—essentially shifting from a computer-centric to a human-centric perspective. This transition—which will begin within the next five years and in full effect within 10–20 years—is discussed in more detail in Chapter 4.

3.2.1 Workstation Performance Trend Table Details & Rationale

Since information system technology projections implicitly risk substantial errors, Table 3-2 warrants further discussion and explanation of the rationale used for its derivation. Although the listed SPECint92 and SPECfp92 values are those of the shipping 300 MHz DEC Alpha 21164 chip [1], this performance is comparable to that achieved or anticipated by the PowerPC, Pentium, MIPS, PA-RISC, and SPARC families. For comparison, a 100 MHz Pentium achieves a SPECint92 of 122 and a SPECfp92 of 93.2; however, the 200 MHz Pentium Pro will achieve a SPECint92 of 366 and SPECfp92 of 283. Extrapolation of the compute performance is based upon plots shown in Sun specifications as well as an assumption of 50 percent per year performance increase. [1]

Although RISC (Reduced Instruction Set Computer) architectures are leading the performance of CISC (Complex Instruction Set Computer) designs, the CISC advances have prevented RISC designs from opening the performance gap originally anticipated; a recent research focus in Very Long Instruction Word (VLIW) architectures may move the CISC philosophy back to the performance forefront. RISC processors have two potential advantages over CISC designs: performance and performance per kilowatt. The power efficiency is reflected in the ARM processor family (used in the Apple Newton) and the PowerPC 603e chip; power efficiency is one of the keys to implementing powerful portable systems as well as the ubiquitous computing paradigm.

As noted previously, multi-processor configurations and greater chip integration either in terms of multi-chip modules (MCMs) or auxiliary processing (e.g, the UltraSPARC which

[1] A more aggressive estimate is made by James Thomas, director of IBM's RISC Microprocessor Division, whose "standard chart … indicates RISC processor performance doubling every 12-18 months" [2].

integrates multimedia capabilities with the processor) imply that the performance of "a" CPU must be viewed in the context of the overall workstation design and application.

Thus, an estimate of greater than 1,000 SPECint92 and SPECfp92 for workstation configurations is fairly conservative since such should be achieved by single-CPU configurations—with multi-processor distributed computing configurations offering significantly more capability. Operating system and language improvements over the interim 5 years will enable efficient use of the multi-processor capabilities.

The amount of memory and disk storage are not currently technology drivers—in the sense that they do not impose algorithmic limits. Hence, while it is anticipated that workstations in five years will have sufficient RAM or disk space, the open issue is *access*—i.e., the time to retrieve the required information. Inclusion of larger caches onboard CPUs, increased network and interconnect bandwidth, faster devices, and improved database access software algorithms should reduce the likelihood of storage availability and bandwidth being significant design drivers.

Humans are visually oriented and, as a result, display technology has been and will continue to be a primary factor in the effectiveness of human-computer interfaces. While "large" (1600x1280 pixels) displays are available with the potential of using multiple screens, the physical constraints imposed by 70–80 pound CRTs or projection systems impose a limit on the display size available to a typical workstation. Large flat-panels displays are on the verge of becoming commodity items due to the demands imposed by HDTV and the associated production economies of scale. Sony and others are currently shipping 25-inch flat-panel televisions (SDTV) with 40-inch versions scheduled for shipping in early 1996. There are a number of competing flat panel technologies (LCD, plasma, FED, etc.) so there is a high probability that the technology will mature and be readily available—and affordable—for workstation-class machines within five years.

While the human-computer interface is currently monotonic—keyboard, mouse / trackball / graphics tablet for human input and display and sound for computer output, the next five years will witness the commercialization of a number of alternate, multi-modal technologies. In this context, "multi-modal" is intended to reflect that multiple mechanisms may be used to achieve the same goal; for example, making a window on-screen active could be accomplished via mouse clicking, keyboard selection, voice command, or tracking the focus of the operator's eye. Since the identified technologies (speech recognition, handwriting recognition/input, eye tracking, and virtual reality) are currently available in focused commercial products, it is reasonable to project that they will become incorporated into the "standard" workstation configuration in the near future—essentially, integrating the workstation and input capabilities into the monitor. The wrinkle in this scenario is the potential for ubiquitous computing to introduce a paradigm shift redefining the human-computer relationship—but that is a topic for Chapter 4. In any event, we should see the continued development of groupware tools so that multiple people can interactively work together to develop mission plans; this groupware will exploit the increased screen real-estate and multi-modal input capabilities.

Unix has many flaws [3]; however, it is the best widely available operating system solution. Unix also has many flavors; one of the better varieties is the Mach micro-kernel architecture which, in addition to being smaller, is dynamically reconfigurable. However, there are efforts underway to introduce new operating system philosophies. Although AT&T's *Plan 9* file-oriented OS is interesting, the most exciting recent development is the object-oriented *Java* language introduced by Sun Microsystems. Java is attractive because the language should facilitate the development of secure operating systems—which is, obviously, attractive for applications such as mission planning. The Java language also has some interesting features such as multi-threading and platform and operating system-independent binaries which would be useful in developing scalable and portable systems. Object-oriented software and operating systems should decrease development time, increase maintainability, and increase reliability and performance. For example, object-oriented map databases will help to resolve some of the current problems in aligning images during mission planning. However, since a dedicated programmer can write FORTRAN (or C) in any language, proper design tools and methodologies are essential to achieving the promise of object-oriented software—as noted by Webster[4].

One of the more interesting trends is that towards open systems. Continuing the trend of X-Windows and POSIX towards platform independence so that software can be (relatively) easily ported to alternate workstations, we now have operating systems such as Solaris, NEXTSTEP, and WindowsNT running on multiple flavors of workstations. Continuing the independence philosophy, OPENSTEP[2] introduces an additional layer of abstraction to permit simultaneous CPU *and* operating system independence. This trend continues with the recently introduced Java language which offers operating system and CPU-independent *binaries* for truly portable software and distributed computing.

The power of a workstation becomes evident when that workstation is connected to other computers and is able to access their knowledge (data) and expertise (software). Hence, network bandwidth and the ability to push (or pull) bits of information from one site to another will continue to play an ever increasing role in workstation architectures and performance. Currently, network technology is transitioning from ethernet towards asynchronous transfer mode (ATM) mechanisms and fiber-optic channels due to the increased bandwidth and flexibility associated with ATM and fiber-optics. Within the next five years this will result in a one to two order of

[2] OPENSTEP is an object-oriented interface and development environment which runs on NeXTSTEP, Solaris, WindowsNT, HP-UX and , therfore, on the hardware platforms supported by those operating systems—including Intel-based PCs, SPARCstations, HP PA-RISC workstations, DEC Alpha workstations, etc.

magnitude increase in bandwidth for both local area (LAN) and wide area (WAN) networking. Such increases enable *distributed* processing and databases.

Conversely, infra-red and picocell RF wireless networks will continue to expand in popularity and availability. Such technology is reflected in Olivetti's IR badge products which are the leading edge of the ubiquitous computing migration. Wireless interfaces will facilitate new products and operational flexibility for products like personal digital assistants (PDAs) and workslates analogous to Alan Kay's dynabook as well as more conventional portable computers.

While the workstation entity will continue to exist, flat-panel displays and wireless interfaces will enable new packages. Hence, displays and other interfaces may be integrated into the *surface* of a desk to create a *workdesk*. Although such systems incorporating a large display area, pen-based input, and voice input may not be commercially available within the next five years, they should be available within ten. The workdesk packaging will enable a more natural, interactive, multi-person, planning process—which, once more, leads to the ubiquitous computing discussed in Chapter 4.

Since the days of paper tape, software and data archiving has progressed through magnetic tape to current CD-ROM and tape cartridge technology. Although CD-ROM writers are currently available on a limited basis, future workstation configurations will incorporate higher density, writable, CD-ROMs rather than the current low-capacity, read-only devices. The increases in network bandwidth in conjunction with multi-level security and secure operating systems will also lead to network-based software and data distribution being a preferred mechanism. Additionally, data replication may not be required within a site if remote sites are accessible containing that information. Conversely, affordable, compact, and fast data storage options may make data replication a preferred design choice.

Finally, the portable computer will continue to increase in capability while simultaneously decreasing in size. The indicated 1995 technology limit is a composite of Apple PowerPC-based and RDI SPARC-based portables. Although these represent impressive capabilities within a four to seven pound package, inclusion of speech recognition, pen interfaces, and wireless networks will dramatically change the concept of a "portable computer."

3.3 Technology Trend Implications

Table 3-2 and Section 3.2 focussed on the evolution of the workstation as it is currently defined. As is discussed in Chapter 4, there are technologies on the horizon which may represent significant long-term capabilities and opportunities; however, the focus of this chapter is the high-probability, low-risk evolution of conventional workstation configurations and their implications with respect to the mission planning system application. The trends of Table3-2 may be summarized as

- increased computational power,
- increased data movement capability,
- increased data storage/access capability,
- increased display resolution and real estate, and
- decreased system size and novel packaging.

Table 3-3 Technology Trend Implications for TAMPS

Feature	*Implication*
Compute Power	• better (higher fidelity) strike planning • faster strike planning • multi-media/virtual reality displays • increased scenario simulation resolution
Flat Panel Displays & Virtual Reality	• workstation layout flexibility • increased screen real-estate • improved human-interface design • increased PDA/portable functionality
Network Bandwidth	• data/graphics transfer architectures (e.g. client/server) • cross-system integration and coordination • distributed processing architectures • increased database consistency • reduced data latency • more portable systems (wireless interfaces)
Database Capacity	• higher-resolution threat characterization • dynamic adaption to changes in the order-of-battle
System Packaging	• improved operator performance • more effective and more mobile systems

The question is, “How will these technology trends impact the mission planning system and how should they be exploited in the system design and development?” As summarized in Table 3-3 and alluded to in the previous section, technology advances will have a significant influence on future TAMPS architectures and performance and, perhaps, the anticipated advances should be factored into the expectations and design of TAMPS 7.0.

From the mission planning perspective, the two most significant advances are those of the CPU performance and network bandwidth. These two factors are “algorithm-drivers” in that they define the strike planning potential and operational procedures of TAMPS. These two factors—in conjunction with CORBA and other interface standards—will enable TAMPS to access the data and expertise of complementary DoD systems. Thus, rather than replicating the capabilities of similar systems such as AFMSS, using a set of well-defined interface standards and system connectivity, required information could be retrieved from the appropriate “expert.” An implicit assumption is that issues and implementation details of multi-level security can be resolved. There are several benefits to such an approach, including:

- reduced code size;
- reduced software maintenance costs;
- increased planning consistency; and,
- improved tactical force coordination.

The disadvantage of such an approach becomes apparent if access to the required resources is denied and TAMPS is forced to operate in isolation. Hence, the system design must support graceful degradation if remote resources or data are denied.

Even in isolation, mission planning performance will be improved by the increased computational and networking capacity associated with technology's advance; the ability to store and access higher-resolution environmental data and to explore potential strikes in greater detail will result in better mission plans.

The interactive nature of mission planning implies that human-computer interface (HCI) design is a key to achieving "optimal" mission plans. Although a number of emerging technologies—as discussed in Chapter 4—will have a tremendous influence in the human-computer relationship, the evolutionary advances in display technology will improve the mission planning performance even if the technology emerging from research labs is not exploited. The four display and packaging technologies which will most impact performance are:

- flat-panel and virtual reality displays;
- portable systems;
- interface standards; and,
- fiber-optic and wireless communications.

Humans are visually oriented and, thus, increasing the amount of information displayed will, in principle, increase the ability of operators to design effective mission plans—providing the interface design presents that information in an accessible style. Virtual reality systems coupled with simulation capabilities will enable "flying" potential missions for plan validation whereas a plethora of flat-panel displays facilitates multi-operator interaction for mission design as well as keeping key information "in view." Ease-of-use is a key ingredient in avoiding egregious and flagrant errors.

Portable systems—such as pilot's assistants—will take mission planning capabilities on the strike and permit real-time refinement and revision of the mission plan. Obviously, such a system needs to have a well-designed interface to avoid pilot overload. Towards this end, speech input/output as well as heads-up displays and other I/O technology will play important roles. Developing software technologies such as intelligent agents will also play an important part in effective system designs.

One of the key aspects of portable systems as well as the fixed systems is the exploitation of interface standards; adherence to hardware interface standards will permit portable systems to use existing avionics or shipboard systems for displays and data transfer. Conversely, adherence to software interface standards (such as CORBA) facilitates structured design, incremental upgrades, and subsettability of capabilities for varying (e.g., portable, shipboard, land-based, etc.) configurations. Interface standards and object-oriented software are also key aspects of modular software, software reuse, and exploiting the capabilities of external/remote systems.

While fiber-optic connections will permit high-bandwidth communications between sites as well as between computers within a site, wireless interfaces will increase the ease-of-use of portable systems by simplifying data downloads and uploads. Wireless communications—via acoustic, infra-red, and RF channels—will also play a role in the non-portable TAMPS configurations as some of the ubiquitous computing technology discussed in Chapter 4 becomes incorporated.

4. Emerging Technologies

Technologies emerging from research labs will redefine the concept of a “workstation.” Thus, whereas Chapter 3 addressed the implications of evolutionary workstation advances to mission planning system design and performance, in this chapter we review some of the emerging technologies and their implications for mission planning.

The increased connectivity due to improving network technologies implies that ever increasing amounts of data will be available for the mission planning process; the problem is to interpret that data to *create* knowledge focused towards achieving a *goal*. Technological advances permit new computing paradigms/philosophies which will better exploit human talents and remote resources.

4.1 Philosophies & Paradigms

As noted in Section 1.2, there are three dominant human-computer interface paradigms: ubiquitous computing, virtual reality, and intelligent agents. Alternately, this corresponds to:

computer-centric: virtual reality;

human-centric: ubiquitous computing; and,

team-centric: intelligent agents.

These philosophies are summarized in Table 4-1. Virtual reality is an extension of current trends towards higher-fidelity interfaces facilitating immersion into the world of the computer. Conversely, the ubiquitous[1] computing—also known as *Ubicomp* and *Embodied Virtuality*—philosophy holds that a mature technology becomes invisible. Thus, rather than the human interfacing to *a* computer—albeit, in a sophisticated and multi-modal fashion—the human is serviced by computers operating in the background. This technology trend is evident in the proliferation of cellular phones, pagers, PDAs (Personal Digital Assistants—e.g., Newtons,

[1] ubiq•ui•tous \yü-'bik-wet-es\ adj (1837) : existing or being everywhere at the same time: constantly encountered: WIDESPREAD

Marcos, etc.), and such. Intelligent agents operate in concert with humans with the agents monitoring data streams and databases and filtering information—i.e., presenting *knowledge* rather than data to the human and allowing the human to focus on knowledge interpretation rather than data retrieval.

Table 4-1: Human-Computer Interface Philosophies

Emerging Philosophies	
Ubiquitous Computing	The premise is that computers should merge into the background so that they become as transparent a technology as writing. To achieve this objective, many interconnected computers are required; however, these computers are of varying degrees of sophistication and capability and appear in a plethora of form factors. Thus, the objective (i.e., the mission plan) becomes the focus rather than the methodology (e.g., access the weapons database, then…).
Virtual Reality	The premise is that a valid approximation of reality can be created into which the human may be inserted. The fictional *Star Trek* holodeck would be an example. Obvious application to TAMPS would be "flying" planned missions or for post-mission analysis. There may also be advantages in terms of the human-computer interaction and mission planning process.
Intelligent Agents	Retrieval of "what you want" rather than the "what you requested" is one application of intelligent agents. Others include monitoring data channels and flagging "significant" information. In other words, the perfect butler. Increasing data volumes make such technologies imperative in identifying, summarizing, and presenting *knowledge* to humans.

Although there are passionate proponents of each philosophy, future mission planning systems will draw upon each of these viewpoints. Virtual reality is especially suited for "flying" potential missions as well as post-mission analysis. The realm of ubiquitous computing is the multi-person, highly-interactive phase of mission and strike planning. Here "the computer" needs to meld into the background since the focus is not the computer, but, rather, assembling the mission plan. This is, to some extent, a natural evolution of the workgroup computing software which is starting to appear in the commercial sector.

Ubiquitous computing[2] —which involves a plethora of computers communicating over wireless as well as fixed channels—will not be mature in the year 2000; however, because of the natural applicability to the mission planning process, inclusion of a subset will still yield operational gains due to the more natural human-centric interface. To illustrate, saying, "Show me a street map of Mogadishu on the wall board. Zoom in over there." is a more natural and faster mechanism than searching through menus or entering textual commands. Similarly, although intelligent agent technology will continue to evolve past the year 2000, the initial implementations will be useful as part of the mission planning process. The ability to automatically monitor and identify critical events or flag potential logistical problems will increase the quality of the resulting mission plans.

4.2 Core Technologies

The computing paradigms will draw on a number of emerging technologies; these can be grouped into four categories:

- computing & network hardware;
- human-computer interfaces;
- software environments & tools; and,
- knowledge representation & processing.

These are discussed in more detail in Table 4-2. Although current technology may not support the wireless link infrastructure required for ubiquitous computing or supply the computational power for intelligent agents or speaker-independent, real-time speech recognition, these deficiencies are on the verge of being overcome—as displayed by some of the ARPA-sponsored

[2] The term "ubiquitous computing" was coined by Mark Weiser while he was at Xerox PARC. Further information on the concept may be found at http://www.ubiq.com/hypertext/weiser/UbiHome.html as well as in Nicholas Negroponte's book, *Being Digital*.

research efforts [5]. The flexibility afforded by high-speed, packet-based, highly-interconnected networks contributes to an data overload worst-case scenario while simultaneously supporting information management solutions to exploit that data.

Human interfaces will become multi-modal in the sense that multiple mechanisms may be used to achieve a given objective; for example, text could be entered via keyboard, handwriting,

Table 4-2: Core Technology Categories

Computing & Network Hardware	Sufficient computing and networking capabilities are essential foundations to implementing the non-computer-centric computing philosophies.
Human Interface Technologies	Rather than data entry and control via keyboard and mouse with computer output via a CRT or LCD, technologies such as voice input, head/eye tracking, tactile interfaces, holographic and stereoscopic 3D displays open new potential for the human-computer interface and, by extension, the human-computer relationship.
Software Environments & Tools	Object-based languages such as Java and interface characterizations such as CORBA and OPENSTEP promise to redefine the software development and definition process. The entity/object-oriented perspective will become embedded in HCIs, knowledge representation, as well as facilitating distributed processing. This viewpoint also leads to “artificial life-forms” which may lead to novel planning approaches as well as implementation of intelligent agents.
Knowledge Processing & Representation	Essential for efficient data access and path planning, this is also one of the key technologies underlying intelligent agents. This also includes aspects of the presentation of knowledge vice data to humans.

or speech. Similarly, text could be “displayed” via synthesized speech, CRT, flat-panel display, wallboard, portable computer/workslate, or summarized in some graphical manner. Interface technologies which promise to be significant in the near future include:

- speech recognition;
- natural language understanding;
- eye tracking;
- keyboard

- mouse/trackball/pad
- graphics tablets/touch-sensitive displays;
- handwriting recognition;
- pen interfaces;
- stereoscopic (3-D) displays;
- holographic displays;
- flat-panel displays;
- gesture recognition;
- etc.

The key to exploiting these interface technologies will be exploiting the *synergy* of a multi-modal interface to create a more natural and efficient mechanism so that the human operator can focus on the product rather than the process and not be constrained by the process.

The software environment and tools are similar to the hardware and networking components in that they will enable the alternate computing philosophies as well as managing the information flow in the conventional computer-centric mode. Object-oriented design methodologies are a key aspect of future computing systems due to the scalability issues associated with global information nets; processing must be partitioned into portable, flexible components rather than designed as a monolithic software entity. Towards this end, technologies such as CORBA (Common Object Request Broker Architecture) provide a layer of abstraction between the client and server which facilitates distributed (networked) processing. OPENSTEP provides a similar layer of abstraction between the development environment and software and the operational hardware and operating system. Other key software technologies include multi-level security and next generation languages such as Sun's Java.

The infrastructure provided by the computers, networks, input/output mechanisms, and software environment requires novel knowledge processing approaches to effectively use and exploit the deluge of data. Thus, advances in knowledge processing are required comparable to those of the physical infrastructure. Order-of-magnitude improvements are projected for object-oriented database access times are projected within the next five years and will be required. Coupled with the advances in human interface mechanisms will be advances in knowledge representation and display. Although an ongoing research area [5], simple changes such as graphical displays rather than textual representations (e.g. of weather maps) allows faster and easier interpretation of data.

Cognitive processing for data fusion is a more elusive goal and has applications ranging from condition-based maintenance to the mission planning problem. One of the more interesting approaches are the so-called "biological systems" [18] which attempt to create artificial life-forms from the bottom using relatively simple components rather than top-down reasoning structures. Such an approach is attractive because it simplifies the design and maintenance problem as well as scaling easier to larger problems. These biologically-based models will probably be a key element in intelligent agent implementation.

4.3 Evolutionary Changes—The Near Future

Although revolutionary changes in the human-computer relationship are imminent, that relationship will change in an evolutionary—albeit, accelerated—fashion. Near term, the synergy between leading-edge commercially available technologies will redefine the workstation as was noted in Chapter 3. In addition to enhancing the capabilities of current workstations in path and mission planning, we will see:

- virtual reality for mission plan validation and analysis;
- object-oriented database access and agents for cross-system coordinat
- groupware and workboards for team-based mission planning; and,
- workslates for data and report entry and editing.

Thus, although the application and processing will functionally be quite similar to the current TAMPS (with the addition of cross-system collaboration), the form factor of the TAMPS workstation will likely have changed from a processor/monitor/keyboard/mouse *unit* to a more dispersed/diffuse/distributed mode. The technologies to implement the identified changes in workstations currently exist. However, they have not been integrated and packaged so that they are easily accessible or available; this situation will change in the near future.

Less bulky and intrusive virtual reality technology will make “flying” missions easier and more comfortable. Combined with higher-fidelity simulations, speech input, and other interfaces, virtual reality will emerge as a valuable tool for mission planning and evaluation—incorporated into the iterative planning stages as well as for final validation. Combined with threat databases, such systems will display risks factors during the virtual or actual flight.

Complementary systems (e.g., AFMSS) will be accessible due to increased network bandwidth and multi-level security protocols. However, efficient exploitation of their data and expertise will be improved by object-oriented databases and agents. To illustrate, the CORBA protocol will enable remote systems to *push* “significant” event notifications to TAMPS based upon *prior* interest in such data. Object-based technology will facilitate packet-oriented networking; this, in turn, will be also be supported by negotiable protocols to push and pull information from remote and local sites.

Mission planning will continue to be an interactive process between groups of humans. As such, the increased display area offered by flat-panel displays will contribute to *groupware* software enabling interaction among team members. Examples of such systems include the Xerox *Liveboard* commercial product. As flat-panel displays become larger and incorporate more modes of input, they will evolve into “workboards”—essentially, enhanced wall-sized versions of palm-sized PDAs such as the Newton. Such systems may include gesture-monitoring among the user input modes. Additionally, the Newton-type technology will evolve into *workslates* featuring wireless links for team collaboration, as well as pen and voice interfaces.

This near-term prediction of the TAMPS operating environment is not very profound; rather, it is a straight-forward extrapolation of current technologies available in commercial products. The common thread is that the mission planning task will be *easier* due to advancing technology. Ease-of-use permits operators to *think* about the mission being planned rather than being wrapped up in the *process* of mission planning. Thus, although the near future will incorporate distributed processing, higher-resolution simulations and modelling, and collaboration with remote systems, the major progress will be the exploitation of the *human* talent (wetware) associated with the planning process.

4.4 Revolutionary Changes—Beyond 2000

Long-term, mission planning systems will continue to exploit the ubiquitous computing and intelligent agent paradigms while simultaneously using virtual reality for mission evaluation. The result will be more timely and higher fidelity mission plans, greater coordination and exploitation of complementary mission planning systems and DoD resources, and a more natural mission planning process. An auxiliary characteristic will be more modular systems and subsystems facilitating incremental upgrades and incorporation of advancing technologies and concepts.

Knowledge representation is a key intelligent agent technology to *interpret* the retrieved data (as well as identifying which data is significant and, therefore, should be retrieved). Thus, for the dynamic application of mission planning, information (data) needs to be analyzed and *summarized* for presentation to the human planner. At a minimum, the information needs to prioritized; the need for knowledge processing became evident during the Gulf war when field commanders were inundated with *information* and tasked to extract *knowledge* from that information. Towards this end, intelligent agent technology will monitor data streams to extract pertinent information. Initially, this technology will be implemented in the form of CORBA protocols wherein data links are established so that changes in requested data sets are identified to the mission planning system. In the long-term, it will redefine the concept of a database since salient information may be scattered across a global network. Of course, key information sets will always have to be maintained locally to preclude problems due to link denial; however, the availability of dynamic data updates so that mission planning is performed with as accurate data as possible is *very* attractive.

The mission planning process of the future will be more free-form—in the sense that the planner will not be constrained to sit in front of a CRT using a keyboard and mouse. Large, wall-mounted displays coupled with ubiquitous computing and multi-modal interfaces will facilitate mixing human-computer interface paradigms. Complementing the flat-panel display technology, holographic displays will permit more insight into the geometry of mission planning via true three-dimensional representations.

The current trend towards packet-based networks will continue and, eventually, incorporate global wireless links. This feature will be exploited by portable mission planning systems used by units and while executing missions. Novel portable system packaging implies that the future "instrumented soldier" may incorporate individual mission planning capabilities. Note that global connectivity of DoD units *must* be used to facilitate *independent* operation towards a common objective rather than centralized control of individual units. Centralized control would not exploit the cognitive abilities of the unit, would be subject to connectivity denial, and is subject to failures due to a top-down implementation—i.e., an inability to scale robustly.

5. Summary and Conclusions

Projecting future technologies has two system design and development benefits:

- characterizing the anticipated operational environment; and,
- identifying technologies which should be permitted as part of the syste evolutionary development.

Revolutionary changes in information systems and human-computer interaction are imminent; incorporating and/or planning for those changes will result in mission planning systems which are robust, effective, and evolvable.

5.1 Mission Planning Trends

Future mission planning systems will exploit the synergy between complementary systems such as TAMPS, AFMSS, AMPS., etc. In the near-term, the mission planning will be performed on the next-generations TAC-5/6 systems—which will approximately correspond to the year 2000 systems projected in Table 3-2. These systems represent approximately a factor of five performance increase relative to current leading-edge systems. The resulting near-term mission planning systems will feature:

- client/server and distributed processing architectures;
- object-oriented software and databases;
- improved multi-modal human-computer interfaces;
- higher resolution mission planning at the unit and force levels;
- more timely mission planning; and,
- capable and portable mission planning systems.

The net effect of the emerging technologies will be mission planning systems which are scalable and adaptable to varying system configurations and external resources and tasking. World wide web technologies will continue to expand and will be incorporated into future systems. System designs and operational procedures will be published in HTML-based formats (or derivatives) for dynamic, platform-independent, on-line, and easily accessible documentation. Embedded applets (e.g., Java) and manipulatable 3-D graphics (e.g., VRML) will improve the quality and usefulness of that documentation.

In the long term, mission planning will include aspects of ubiquitous computing, virtual reality, and intelligent agents. These technologies will exploit advances in CPUs, sensors, and networking—as well as software and algorithm technologies.

5.2 Exploiting Technology Trends

Acknowledging that technological advances will result in a dramatic redefinition of workstations and information systems, in general, and mission processing systems and architectures, in particular, we seek to design systems which are evolvable so that systems are still useful in the future and their capabilities may be easily incorporated into future configurations. Thus, the system development mantra should be "*modularity and open systems.*" The "modularity" aspect implies that designs should exploit object-oriented technology and support distributed computing architectures. The "open systems" objective reflects a desire to avoid bad decisions—i.e., betting the farm on the wrong operating system, network technology, or processor family. Conversely, like the turtle, sometimes you have to stick your neck out—and make a decision—to make progress.

So, what technologies hold the most promise? From the modularity perspective, web-based systems and distributed computing which exploits increased interconnectivity and network bandwidth appear to be obvious choices. Hence, CORBA should be featured in future mission planning system architectures along with object-oriented technologies[1] since it introduces a layer of abstraction (i.e., flexibility) between system components.

Since CORBA IDL (Interface Description Language) bindings are available for many languages, language selection is an open issue with Ada95 and C++ being obvious candidates. However, OPENSTEP (i.e., Objective-C and Display-Postscript) may be an attractive alternative since it introduces an additional layer of abstraction—allowing the portability between operating systems (NEXTSTEP, Solaris, Mach, WindowsNT, Digital UNIX) and workstations which support those OS (Intel, SPARC, PA-RISC, Alpha, etc.).

[1] WARNING:Object-oriented development is *not* a panacea and requires proper design methodologies and tools for successful system implementation—just like procedurally-based approaches.

Exploiting emerging technologies will involve a mapping from current and anticipated performance objectives. Hence, the architecture design process should involve an assessment of future operational modes to identify appropriate technologies (e.g., HCI) and how they can be incorporated into mission planning systems as those technologies mature.

5.3 Demonstration Projects

Incorporating emerging technologies into the next generation mission planning systems will improve the performance of those systems; however, because these technologies are emerging, there is an associated development risk. To mitigate the development risk, proof-of-concept demonstrations of key technologies should be developed. Such demonstration projects will also help to define and refine the development methodologies and tools required for distributed system development. Key development projects should include:

- CORBA demonstration linking the TAMPS 6.0 and AFMSS systems;
- multi-modal human-computer interface technologies;
- object-oriented map database demonstration;
- intelligent agent technology applicability assessment;
- distributed computing exploration; and,
- development methodologies demonstration and documentation.

Although very immature at this time, the Java app/applet technology appears to be useful for scalable and portable system development and may, therefore, also warrant some attention. There may also be operational advantages to *dynamic* distributed processing based upon such technology. If a migration to non-workstation platforms (i.e., Intel-based PCs) is a valid architectural option, an exploration of OPENSTEP applicability may also be appropriate.

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